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Agronomic performance and nutritional status of arrowroot in response to nitrogen fertilization with bovine manure

Desempenho agronômico e estado nutricional de araruta em resposta a adubação nitrogenada com esterco de bovino

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Abstract

Arrowroot is a plant little studied in terms of fertilization and nutritional status. This study evaluates the effect of nitrogen fertilization with bovine manure on the nutritional status of arrowroot plants by means of physiological indices, on yield, and on the export of nutrients by rhizomes of two arrowroot varieties. The experimental design was a randomized block design in a 2 x 6 factorial scheme, with four replicates. Factors consisted of two arrowroot varieties (‘Comum’ and ‘Seta’) and six nitrogen rates (0, 75, 150, 300, 600, and 900 kg ha^{-1}). At 120 days after planting, the following were evaluated on the second fully expanded young leaf in the main stem: SPAD Index, chlorophyll Index, flavonoid Index, nitrogen balance, and leaf nutrient content. The SPAD and chlorophyll indices correlated positively with total leaf N content and commercial rhizome yield, but there was no significant difference between varieties. The SPAD 502 and Dualex readings were efficient in diagnosing N status in arrowroot plants. Commercial rhizome yields were 47.9 t ha^{-1} for variety ‘Seta’, with 778 kg ha^{-1} N; and 43.2 t ha^{-1} for variety ‘Comum’, with 900 kg ha^{-1} N.

Additional keywords: Dualex; *Maranta arundinacea;* mineral nutrition; nitrogen; SPAD.

Resumo

A araruta é uma planta pouco estudada quanto à adubação e ao estado nutricional. Com esse trabalho objetivou-se avaliar o efeito da adubação nitrogenada com esterco de bovino no estado nutricional das plantas, por meio índices fisiológicos, na produtividade e na exportação de nutrientes pelos rizomas de duas variedades de araruta. O experimento foi em delineamento de blocos casualizados e esquema fatorial 2 x 6, sendo duas variedades de araruta (‘Comum’ e ‘Seta’) e seis doses de nitrogênio (0, 75, 150, 300, 600 e 900 kg ha^{-1}), com quatro repetições. Aos 120 dias após o plantio avaliou-se, na segunda folha jovem totalmente expandida no perfilho principal, o Índice SPAD, Índice de clorofila, Índice de flavonoides, o balanço de nitrogênio e teor foliar de nutrientes. Os índices SPAD e de clorofila correlacionaram positivamente com teor de N total nas folhas e com a produtividade de rizomas comerciais, mas não houve diferença significativa entre as variedades. As leituras com SPAD 502 e Dualex foram eficientes para o diagnóstico do estado de N nas plantas de araruta. As produtividades de rizomas comerciais foram de 47,9 t ha^{-1} para ‘Seta’ com 778 kg ha^{-1} de N e 43,2 t ha^{-1} para ‘Comum’ com 900 kg ha^{-1} de N.

Palavras-chave adicionais: Dualex; *Maranta arundinaceae;* nitrogênio; nutrição mineral; SPAD.

Introduction

Arrowroot (*Maranta arundinacea* L.) is an herbaceous, perennial, rhizomatous plant originating in tropical regions of South America, occurring from the northeast to the south of Brazil. Its rhizomes contain starch with excellent digestibility and absence of gluten, being recommended for celiac people or people with restriction to this protein. Arrowroot starch has medicinal and culinary use, thus standing out when compared to conventional or similar starches. Moreover, it is of great interest for food industries (Cunha, 2016; Santos et al., 2019). The crop develops in different types of soil and climate, and can be explored in small areas, mainly by family farming, generating employment and income (Sediyama et al., 2019).

Unconventional vegetables, such as arrowroot, have not received due attention from research and, therefore, the knowledge and use of these species are still limited. In recent years, arrowroot has been conquering the market for the quality of its starch. Therefore, research is necessary to rescue and expand cultivation areas, especially addressing genetic improvement of the plant and phytotechnical practices, indicating productive genotypes and production systems, mineral plant nutrition, and adequate levels of nutrients. Some studies on arrowroot have been developed in recent years, mainly regarding crop management systems, plant nutrition (Cesar et al., 2015; Santos et al., 2019), phenotypic characterization (Guilherme et al., 2016), and phenological stages of the plant (Brito et al., 2019).

Arrowroot is a very resistant plant that is adapted to organic cultivation, a modality that is growing in Brazil and worldwide. This cultivation system makes use of organic fertilizer, increasing total soil organic carbon and nitrogen stocks. This is an important strategy for maintaining soil quality (Leite et al., 2010), in addition to increasing the mineralization potential of nutrients and their availability to plants. Adequate supply of nutrients to the soil by organic fertilizer favors crop yield, resulting in plants with qualitative characteristics similar to those of plants cultivated with mineral fertilizers (Alencar et al., 2013). The yield of plants under organic management is compatible with that obtained under a conventional system. In a conventional cultivation system, maximum arrowroot rhizome yield (47 t ha^{-1}) was obtained with 157 kg ha^{-1} nitrogen (Cesar et al., 2015). Nevertheless, higher losses of organic carbon occur in that type of system, where crops are fertilized only with mineral fertilizer. These losses lead to a negative soil carbon balance (Steiner et al., 2012).

Nitrogen is one of the nutrients most required by most agricultural crops, and is exported in greater quantities, thus the need to replace it with each production cycle. As in other crops, it is a fundamental nutrient for vegetative plant growth and starch accumulation in rhizomes. Notwithstanding, there are still few technical recommendations and indications for fertilization and nutrition in arrowroot (Cesar et al., 2015).

Leaf analysis and visual assessment are tools that help in diagnosing the nutritional status of plants. However, other nondestructive methods have been used to estimate chlorophyll and nitrogen contents as indicators (Coelho et al., 2012; Santos et al., 2019). These methods of instantaneous measurement of leaf chlorophyll and nitrogen (SPAD Minolta or Dualex, Force-A) support the analysis of crop performance under nitrogen fertilization and determine the need for nitrogen fertilization in various crops (Segatto et al., 2017).

Given the above, this study evaluates the effect of nitrogen fertilization with bovine manure on the nutritional status of arrowroot plants by means of physiological indices, on yield, and on the export of nutrients by rhizomes of arrowroot varieties ‘Comum’ and ‘Seta’.

Material and methods

The experiment was conducted in Oratorios city, Minas Gerais State, Brazil (20º25'50" S, 42º48'20" W, altitude of 500 m), from October 2016 to August 2017. According to Köppen and Geiger, the climate of the region is classified as “Aw”. The average annual maximum temperature is 21.6 °C, and the average annual minimum is 19.5 °C; average rainfall is 1162 mm. In the experimental period, the recorded rainfall was 890.72 mm, distributed throughout the rainy season.

The soil of the experimental area was classified as Red-Yellow Cambic Argisol, terrace phase, clayey. In the 0-20 cm layer, the soil had the following characteristics: pH (water 1:2.5) = 6.1; organic matter = 26.0 g kg^{-1}; P (Mehlich 1) = 26.9 mg dm^{-3}; K = 290 mg dm^{-3}; Ca^{2+} = 2.4 $cmol_c$ dm^{-3}; Mg^{2+} = 1.2 $cmol_c$ dm^{-3}; Al^{3+} = 0.0 $cmol_c$ dm^{-3}; H+Al = 2.1 $cmol_c$ dm^{-3}; SB = 3.98 $cmol_c$ dm^{-3}; CEC(t) = 4.3 $cmol_c$ dm^{-3}; CEC(T) = 6.4 $cmol_c$ dm^{-3}; V = 67% and m = 0.0%; P-rem = 45.4 mg L^{-1}; and (in mg dm^{-3}): Zn = 7.2; Fe = 80.3; Cu = 2.2; and B = 0.3.

The experimental design was a randomized block design in a 2 x 6 factorial scheme, with four replicates. Factors consisted of arrowroot varieties (‘Comum’ and ‘Seta’) and N rates (0, 75, 150, 300, 600, and 900 kg ha^{-1}) applied in the form of tanned bovine manure. Arrowroot seedlings were obtained from the UFV Germplasm Bank and standardized by size (approximately 10 cm long).

The soil was prepared by plowing, harrowing, and furrowing, at a depth of 30 cm. Planting and topdressing fertilizations were carried out with bovine manure, with 2/3 of the rate being applied one week before planting, and 1/3 of the rate being applied at 50 days after planting (DAP). The manure had the following characteristics (in g kg^{-1}): N = 24.0; P = 6.4; K = 23.0; Ca = 11.7; Mg = 1.9; S = 4.1; and O.M. = 29.2; C/N = 12.15; and (in mg kg^{-1}): Zn = 110; Fe = 2,359; Mn = 303; Cu = 34; B = 14, pH = 9.23; and Na = 0.25%; air humidity (%) = 57.34; oven humidity at 75 ºC (%) = 63.56.

Planting was carried out by means of rhizomes or healthy pieces of rhizomes, standardized by size, using those with an average weight of 40 to 60 grams. The rhizomes were planted in furrows of approximately 3.0 cm depth. Spacing was 0.80 m between rows and 0.40 m between plants in the row. The plot area was 12.8 m^2 (3.2 x 4.0 m), with 40 plants distributed in four rows of 4.0 m in length.

Drip irrigation was performed during periods of prolonged drought. For that, we used tapes perforated every 0.2 m in the planting rows, applying a water depth of about 20 mm per week. Invasive plants were controlled by manual weeding with a hoe until the rows were closed, that is, 120 days after planting. Plants started emerging less than 15 days after planting. Within 30 days, all plants had tillers. Hilling was performed at 90 DAP.

At 120 DAP, the following were evaluated on the second fully expanded young leaf in the main stem, in six useful plants per plot: SPAD Index, chlorophyll Index (ICHL), flavonoid Index (IFLV), and nitrogen balance index (NBI). This second leaf was chosen randomly to analyze the nutritional status, since there is no specific indicator leaf for arrowroot.

The SPAD Index was determined using a portable chlorophyll meter SPAD 502 (Minolta) in four positions in the middle third of the leaf blade (two readings on the right edge and two on the left), considering the average of the readings made on each leaf. Chlorophyll (ICHL), flavonoid (IFLV) and nitrogen balance (NBI) indexes, obtained by the relation between the readings of ICHL and IFLV, were determined with a portable meter Dualex (Force-A), considering the middle third of the same leaf blade.

The evaluated leaves were collected, packed in a paper bag, and placed in an oven with forced air circulation at 65 ºC for approximately 72 hours until constant weight. After drying, the leaves were ground in a Wiley mill equipped with a 20-mesh sieve, packed in paper bags, and taken to the laboratory to determine the levels of N, P, K, Ca, Mg, S, Mn, B, Zn, and Fe.

At the end of the cycle (303 DAP), the plants were harvested with a hoe. Ten (10) useful plants were harvested per plot, being evaluated for the yields of large, medium, small, and off-type rhizomes, which were estimated in t ha^{-1}. Rhizomes obtained in the first three classes were considered as commercial yield. The number of rhizomes per plant was evaluated. The calculation of dry matter of rhizomes and shoots considered a sample composed of rhizome classes and shoot samples from each plot.

The dry material was ground and analyzed for macro- and micronutrient contents. The quantities of macronutrients exported were calculated based on the production of dry matter of rhizomes per hectare and on the contents of these nutrients. Analysis of variance and regression analysis were performed using SAEG 9.1 software (SAEG, 2007). The regression model was chosen based on the biological significance and on the significance of the coefficients. Means were compared by the t test at 10% significance.

Results and discussion

Nutritional status of plants

For variety 'Comum', total leaf nitrogen (N) content increased with the increase of applied N rates, following a quadratic model, up to the maximum value of 34.6 g kg^{-1}, obtained with 563 kg ha^{-1} N. For variety 'Seta', the response to the increase in N rates was constant at an average value of 26.9 g kg^{-1} (Figure 1A). The values found in this research are similar to those obtained by Pereira (2019), who studied the same arrowroot varieties. At 105 and 135 days after planting, the authors observed the following levels of total shoot N: 35.8 and 29.5 g kg^{-1} for variety 'Comum', and 34.6 and 26.0 g kg^{-1} for variety 'Seta', respectively. The lowest rates and the absence of N affected tillering and plant height. Although no reference values were found in the literature to assess the nutritional status of N in arrowroot, leaf N content at 120 DAP was higher than 25.0 g kg^{-1}, which Raij et al. (1997) consider satisfactory for most plants.

The SPAD and ICHL indices did not differ significantly between varieties. These indices increased linearly as a function of N rates, with the highest values (44.74 for SPAD and 34.80 for ICHL) being obtained with the highest applied N rate (900 kg ha^{-1}) (Figures 1B and 1C). The IFLV index was higher in variety 'Seta' (1.25) than in variety 'Comum' (1.01); however, it did not respond to N rates.

The NBI index showed a similar response to total leaf N content for the two arrowroot varieties. For variety 'Comum', the values followed a quadratic trend, where the maximum value (35.47) was obtained with 629 kg ha^{-1} N. For variety 'Seta', the average value of 21.72 was constant (Figure 1D).

The relationship between chlorophyll and flavonoid contents has been shown to be a good indicator of the the nutritional status of N in wheat (Cartelat et al., 2005) and potato (Coelho et al., 2012). In arrowroot crop, this relationship differed between varieties, being more significant in variety 'Comum' than in variety 'Seta'. This is explained by the correlation between the characteristics evaluated, since only for variety 'Comum' the NBI index correlated positively with total leaf N content and commercial rhizome yield (NBI of 0.82 and 0.65, respectively) (Table 1).

The SPAD index correlated positively with total leaf N content, chlorophyll index, N balance index, and commercial rhizome yield. Other positive correlations were observed between chlorophyll index and total leaf N content; chlorophyll index and N balance index; and chlorophyll index and commercial rhizome yield (Table 1).

Plant nitrogen is used in the synthesis of several structural compounds, such as: lipids, amino acids, and proteins used in photosynthesis (Tuncay et al., 2011). In addition, N is the main component of chlorophyll, so the presence of N in the leaves favors CO2 assimilation during photosynthesis, increasing net photosynthetic rate and, consequently, chlorophyll content (Li et al., 2013).

The correlation between leaf N content and commercial rhizome yield was lower than that between SPAD and chlorophyll indices (Table 1); therefore, it presented reduced potential as an indicator of the nutritional status of plants and, consequently, for the definition of the N rate. These results were similar to those obtained by Coelho et al. (2012), who considered that leaf N content is not a sensitive indicator of the nutritional status of potato plants, correlating less with yield when compared to the SPAD 502 evaluation.

The SPAD index can vary with the position of the leaves and with the time of plant evaluation (Godoy et al., 2010). The results found in this research at 120 DAP (41.59 and 44.75) are compatible with those found by Moreno et al. (2017) for 'Comum' arrowroot (42.46) at 100 days after planting. Thus, using the SPAD index or the Dualex between 100 and 120 DAP can help in determining chlorophyll and N content during early formation of rhizomes, with enough time for N replacement, and enables predicting the final yield of arrowroot rhizomes.

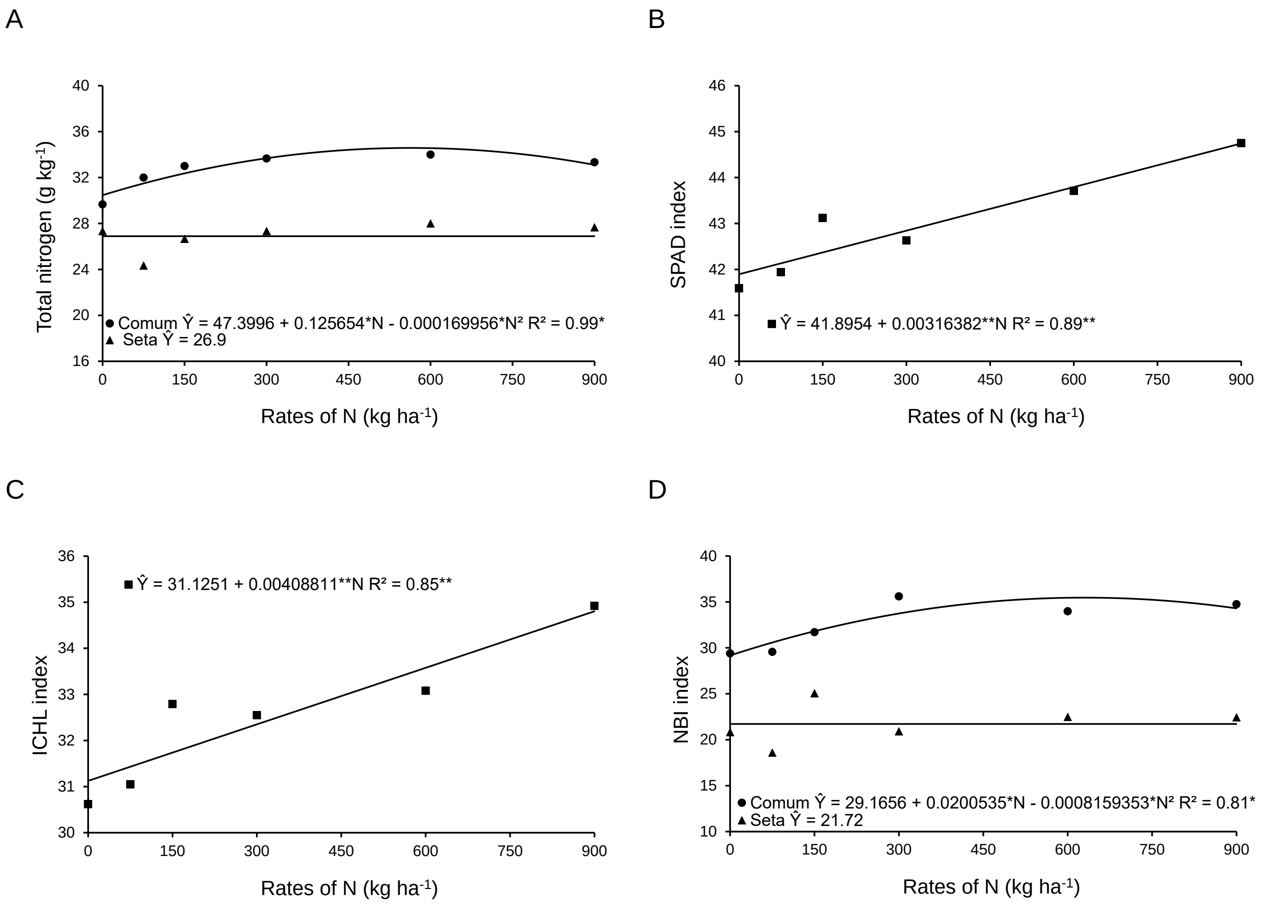

Figure 1 – Total nitrogen (A), SPAD index (B); chlorophyll index (C) and nitrogen balance index (D) on the second leaf of arrowroot stem main of the cultivars 'Comum' and 'Seta' at 120 days after planting as function of nitrogen (N) rates as bovine manure.
**; *Significant by t test at 1% and 5% of probability, respectively

Table 1. Pearson's linear correlation coefficients (r) between the SPAD index, chlorophyll index, nitrogen balance index and total N content in the leaf, determined on the second leaf at 120 days after planting, with the total N content and the commercial yield of arrowroot rhizomes in the 'Comum' and 'Seta' varieties

Characteristics	Total N content	SPAD index	Chlorophyll index	Commercial yield of rhizomes
			var. Comum	
SPAD index	0.86*	--	0.95**	0.86*
Chlorophyll index	0.95**	0.95**	--	0.85*
N balance index	0.82*	0.89**	0.95**	0.65*
Total N content	--	0.86*	0.94**	0.82*
			var. Seta	
SPAD index	0.75*	--	0.76*	0.84*
Chlorophyll index	0.76*	0.98**	--	0.93*
N balance index	0.55ns	0.87*	0.87*	0.28ns
Total N content	--	0.75*	0.76*	0.44ns

** and *: Significant at 1 and 5% of probability, respectively; ns: no significant

The results show that the SPAD 502 and Dualex readings adequately estimate the intensity of the green color of 'Comum' and 'Seta' arrowroot leaves. Therefore, these field readings can substitute with good precision laboratory determinations of total N content in arrowroot, using a simpler, nondestructive, and less expensive technique.

N rates did not significantly affect some levels of nutrients in the leaves of the two arrowroot varieties and, in other cases, mathematical models did not fit adequately. Thus, the leaf contents of macronutrients and micronutrients, except for N, will be presented in tables.

Arrowroot variety 'Comum' had a higher leaf phosphorus (P) content (2.7 g kg^{-1}) than variety 'Seta' (2.4 g kg^{-1}). For the latter variety, P content did not differ as a function of the applied N rates (Table 2).

Leaf potassium (K) content was similar in both varieties, averaging 23.20 g kg^{-1}, and showed a slight increase with increasing N rates (Table 2). Despite the lack of specific reference values in the literature, Raij et al. (1997) consider K levels above 23.0 g kg^{-1} adequate for most plants. Potassium (K) is a nutrient that is easily mobilized and is readily redistributed from older leaves to new growing organs. Regarding the behavior of N, P, and K in plant decomposition and release of nutrients in plant residues, K is the nutrient more quickly released from the residue to the soil during mineralization (Leite et al., 2010). Due to its high mobility in plants, also in the soil, K content can vary between leaves of the same arrowroot tiller. Thus, knowing the indicator leaf is essential to assess the critical level of nutrients in this crop.

Table 2 – Macronutrient content in arrowroot leaves of 'Comum' (V1) and 'Seta' (V2) varieties at 120 days after planting as function of nitrogen (N) rates as bovine manure.

N (kg ha^{-1})	P		K		Ca		Mg		S	
	---------- (g kg^{-1}) ----------									
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
0	2.93a*	2.20a	22.07b		3.70b	4.13a	3.23ab	2.20a	2.83ab	2.70a
75	2.62ab	2.47a	26.65ab		4.27ab	3.93ab	3.02 b	2.30a	2.57 b	3.37a
150	2.73ab	2.53a	24.07a		4.40ab	3.20 b	3.20ab	2.27a	2.30 b	2.70a
300	2.31b	2.27a	22.33ab		4.53ab	4.20a	3.10 b	2.33a	2.77ab	2.63a
600	2.67ab	2.50a	23.93ab		4.13ab	4.10a	3.13 b	2.30a	3.40a	3.10a
900	3.00a	2.50a	24.20a		4.57a	4.00ab	3.53a	2.33a	3.03ab	3.03a
Average	2.71A	2.41B	23.20		4.27A	3.93B	3.20A	2.29B	2.82A	2.92A
C.V. (%)	9.94		5.48		8.07		5.76		10.05	

*Means followed by the same lowercase and uppercase letters in the columns and lines, respectively, do not differ by Tukey ($p > 0.05$).

Leaf Ca and Mg contents increased with the applied N rates and were higher in variety 'Comum'. Leaf S contents did not change with increasing N rates and were similar in both varieties (Table 2). No reference nutritional standards for arrowroot were found in the literature consulted, which would allow a comparison with the leaf macronutrient contents presented here. Thus, it is believed that these values are valid as nutritional reference standards for arrowroot varieties 'Comum' and 'Seta'.

The increase in macronutrient leaf contents with increasing rates of N provided by bovine manure is probably due to the relatively long cycle of arrowroot, which allowed time for mineralization and availability of nutrients to plants. These plants absorb the nutrients from the soil solution in ionic form, in different quantities, with each species having a different strategy for its acquisition (Madi et al., 2015).

Leaf micronutrient contents did not respond to N rates; however, there was a difference between varieties, with 'Comum' arrowroot having a higher micronutrient content in the dry matter of leaves when compared to 'Seta' arrowroot (Table 3). For all micronutrients, despite not having found reference values in the literature, the leaf contents found were within the appropriate range for most plants. According to Raij et al. (1997), reference values are (in mg kg^{-1}): Zn (20-100); Fe (30-200); Mn (25-250); Cu (5-15); and B (20-60).

Rhizome yield

The yield of large rhizomes differed between varieties, with arrowroot variety 'Seta' producing a higher quantity (18.2 t ha^{-1}) regardless of the applied N rate. Variety 'Comum' responded significantly to N rates, reaching the maximum yield of 16.0 t ha^{-1} with 900 kg ha^{-1} N (Figure 2A). Regarding morphological characteristics, arrowroot variety 'Seta' produced larger rhizomes with more distant internodes compared to variety 'Comum'. This fact suggests the existence of genetic variability among varieties, which implies, among other characteristics, higher yield and, possibly, higher starch content, since the cultivation environment was the same.

The yields of medium and small rhizomes increased linearly with N rates regardless of the variety, reaching the highest value (14.2 and 8.5 t ha^{-1}, respectively) with 900 kg ha^{-1} N (Figures 2B and 2C). The maximum yield of off-type rhizomes did not differ between varieties, and showed a quadratic response to N rates, reaching a maximum value of 3.6 t ha^{-1} with 634 kg ha^{-1} N (Figure 2D).

Table 3 – Micronutrient content in arrowroot leaves of 'Comum' (V1) and 'Seta' (V2) varieties at 120 days after planting as function of nitrogen (N) doses as bovine manure.

N (kg ha^{-1})	Zn		Fe		Mn		Cu		B	
	(mg kg^{-1})									
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
0	23.33a*		112.00a		277.00b	212.33a	7.67b	5.33a	21.20a	
75	22.75a		103.25a		389.75a	228.33a	7.75b	5.33a	23.26a	
150	23.67a		102.17a		339.00a	171.00a	8.33ab	6.00a	22.38a	
300	22.17a		100.00a		329.33a	205.67a	9.00a	6.00a	22.30a	
600	23.83a		103.33a		348.00a	176.33a	8.33ab	5.67a	23.23a	
900	24.17a		106.00a		326.33a	171.33a	8.67ab	5.67a	21.83a	
Average	25.47A	21.17B	117.64A	91.28B	334.90A	194.11B	8.29A	5.67B	23.97A	20.77B
C.V. (%)	8.94		16.95		14.62		9.06		8.86	

*Means followed by the same lowercase and uppercase letters in the columns and lines, respectively, do not differ by Tukey ($p > 0.05$).

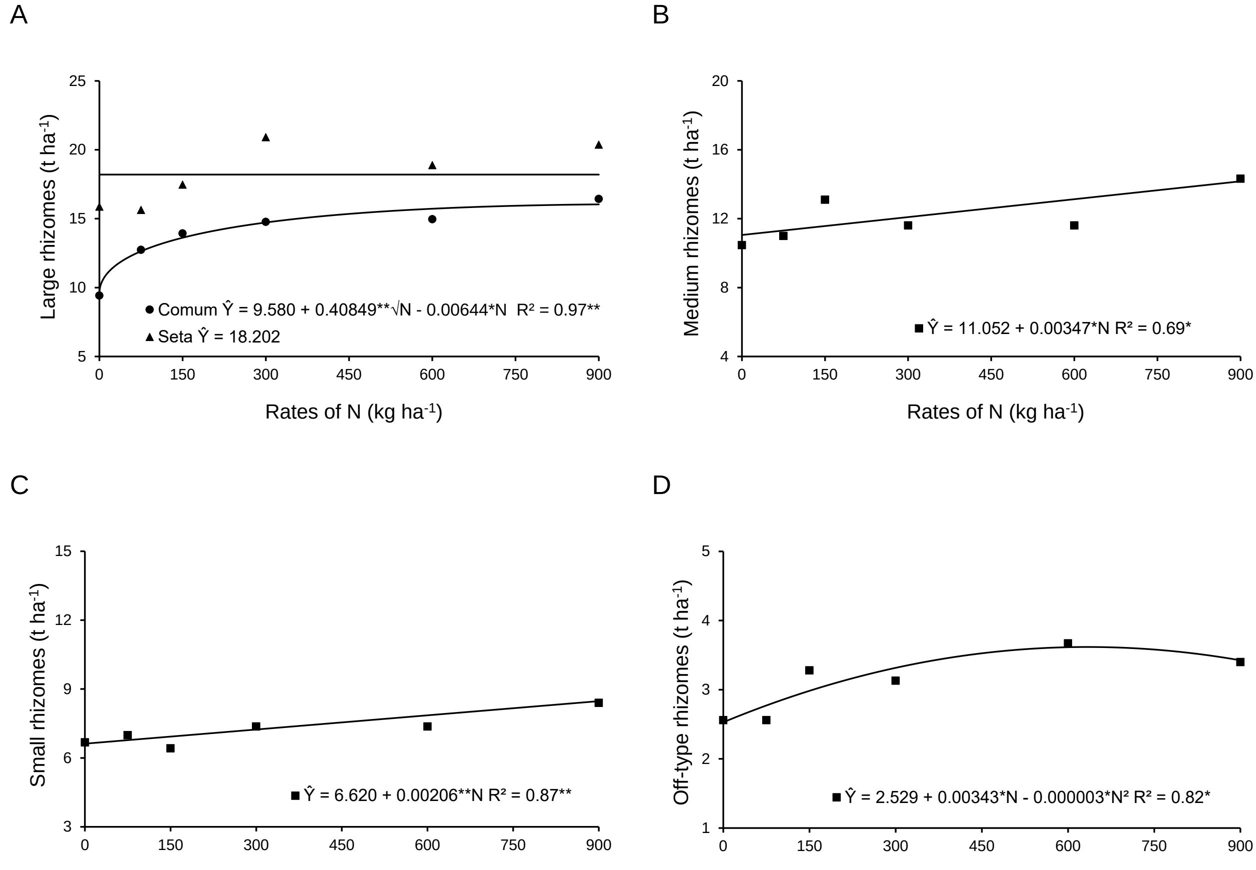

Figure 2 – Yield of large (A), medium (B), small (C) and off-type rhizomes (D) of arrowroot, varieties 'Comum' and 'Seta' as function of nitrogen (N) rates as bovine manure.
**; *Significant by t test at 1% and 5% of probability, respectively.

Commercial rhizomes yield, measured by both fresh and dry weight, was influenced by N rates and arrowroot varieties (Figures 3A and 3B). Variety 'Comum' showed maximum yield of 43.2 t ha^{-1} with 778 kg ha^{-1} N; variety 'Seta' produced 47.9 t ha^{-1} with 900 kg ha^{-1} (Figure 3A). The dry mass yield of commercial rhizomes showed the same trend as the fresh mass yield, that is, an increasing response to N rates. The maximum values observed for varieties 'Comum' and 'Seta' were, respectively, 13.1 t ha^{-1} and 17.0 t ha^{-1}, both obtained with application of 900 kg ha^{-1} N (Figure 3B). In Biri (*Canna edulis* Kerr-Gawler), nitrogen fertilization also induced higher rhizome yield, while phosphorus and potassium application did not alter crop yield over 150 days (Silva & Mongelo, 2008). The amount of nutrients absorbed does not always reflect biomass production, with likely luxury consumption levels under conditions of high nutrient availability (Madi et al., 2015).

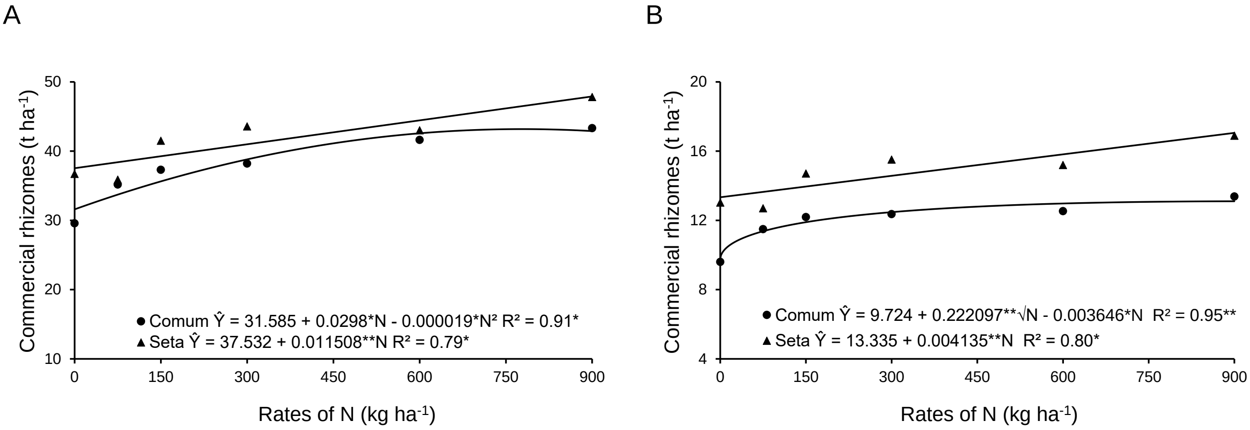

Figure 3 – Commercial rhizomes yield of arrowroot 'Comum' and 'Seta' expressed in fresh mass (A) and dry mass (B) as function of nitrogen (N) rates as bovine manure.
**; *Significant by t test at 1% and 5% of probability, respectively

Nutrient export

Arrowroot exports considerable amounts of soil nutrients, producing more than 40.0 t ha^{-1} of commercial rhizomes. Considering that the highest dry matter of commercial rhizomes was 13.1 t ha^{-1} for variety 'Comum' and 17.0 t ha^{-1} for variety 'Seta', both obtained with 900 kg ha^{-1} N (Figure 3A), the quantities of macronutrients (kg ha^{-1}) and micronutrients (g ha^{-1}) exported by rhizomes were, in decreasing order: 272.99 and 320.91 (K); 107.06 and 168.90 (N); 34.79 and 38.85 (P); 14.72 and 16.89 (S); 10.71 and 13.51 (Mg); 2.68 and 3.38 (Ca); 963.50 and 658.71 (Fe); 160.58 and 168.90 (Zn); 80.29 and 168.90 (Mn); 53.53 and 33.78 (Cu); and 17.40 and 21.96 (B), respectively, for varieties 'Comum' and 'Seta'. Tables 4 and 5 show the quantities exported according to the assessed N rate.

Table 4 – Exported amounts of the macronutrients by rhizomes of arrowroot 'Comum' (V1) and 'Seta' (V2) as function of nitrogen (N) rates as bovine manure.

	N		P		K		Ca		Mg		S	
N (kg ha^{-1})	(kg ha^{-1})											
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
0	124.76	130.35	34.55	28.68	218.81	281.56	3.84	0.00	10.56	10.43	15.36	18.25
75	149.40	101.61	34.48	30.48	252.82	274.34	2.30	5.08	11.49	10.16	14.94	13.97
150	97.51	132.44	37.79	33.85	277.91	264.89	4.88	4.41	12.19	11.77	15.85	19.13
300	135.98	108.61	42.03	37.24	301.63	285.49	4.94	7.76	12.36	12.41	13.60	20.17
600	112.77	139.68	40.10	32.59	295.71	285.57	5.01	6.21	12.53	12.42	16.29	12.42
900	107.06	168.90	34.79	38.85	272.99	320.91	2.68	3.38	10.71	13.51	14.72	16.89
Average	121.25	130.27	37.29	33.61	269.98	285.46	3.94	4.47	11.64	11.78	15.12	16.80

A study conducted with the same varieties revealed similarity for N values and considerable differences for the other macronutrients. To meet the demand for macronutrients accumulated in the rhizomes, the following quantities (kg ha^{-1}) should be exported by rhizomes in the first year of cultivation: 420.20 and 481.00 (K); 103.20 and 168.50 (N); 65.20 and 119.40 (S); 46.00 and 74.25 (P); 37.90 and 58.50 (Mg) and 15.30 and 18.50 (Ca), respectively, for varieties 'Comum' and 'Seta' (Pereira, 2019). This difference in values can be attributed to cultivation and fertilization conditions. In the present study, cattle manure was used as the exclusive source of fertilizer, while Pereira (2019) used chemical fertilizer.

The export of macronutrients by rhizomes presented the following sequence: K > N > P > S > Mg > Ca, regardless of the variety (Table 4). In a study conducted with the same varieties, rhizomes accumulated macronutrients in the following decreasing order: K > N > S > P > Mg > Ca, also regardless of the variety (Pereira, 2019). Therefore, the difference between the two studies is related to S and P. The export of micronutrients by rhizomes presented the following sequence: Fe > Zn > Mn > Cu > B (Table 5).

Table 5 – Exported amounts of the micronutrients by rhizomes of arrowroot 'Comum' (V1) and 'Seta' (V2) as function of nitrogen (N) rates as bovine manure.

N (kg ha^{-1})	Zn		Fe		Mn		Cu		B	
	(g ha^{-1})									
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
0	153.55	130.35	374.28	612.65	28.79	78.21	47.99	39.11	2.88	44.32
75	183.87	139.71	563.11	711.26	22.98	165.11	34.48	38.10	14.94	16.51
150	170.65	117.73	1133.58	544.49	73.13	73.58	36.57	44.15	15.85	19.13
300	173.07	155.16	494.48	682.70	37.09	232.74	61.81	62.06	16.07	4.65
600	187.95	139.68	751.80	589.76	137.83	124.16	50.12	31.04	42.60	20.18
900	160.58	168.90	963.50	658.71	80.29	168.90	53.53	33.78	17.40	21.96
Average	171.61	141.92	713.46	633.26	63.35	140.45	47.41	41.37	18.29	21.12

The amounts of nutrients extracted by rhizomes must be returned to the soil, while the amounts extracted by shoots can return to the soil from plant decomposition and release of nutrients from crop residues for the new planting. Another possibility would be to use shoots as crushed forage, since the leaves and stems contain a reasonable amount of nutrients at harvest (Coelho, 2003; Vieira et al., 2015).

Data on the export of nutrients by arrowroot rhizomes are scarce (Vieira et al., 2015). However, in 'Japanese' taro, an unconventional rhizomatous plant from the family Araceae, the export of N, P, and K by cormels was 132.9; 24.0; and 206.2 kg ha^{-1} for a commercial rhizome yield of 29.1 t ha^{-1} (Sediyama et al., 2009). Still in 'Japanese' taro, the export of N, P, and K by rhizomes was: 193; 47.0; and 443 kg ha^{-1} for a yield of 66.0 t ha^{-1} (Puiatti et al., 1992). These results show that the amounts of nutrients exported by arrowroot and taro rhizomes were equivalent, especially considering the yield of rhizomes of each species, as both are quite rustic and respond to soil fertility.

The present study applied 600 kg ha^{-1} N to the soil, corresponding to 60.0 t ha^{-1} bovine manure with 40% moisture and 2.4% N. This application enabled excellent vegetative development, associated with a commercial arrowroot rhizome yield around 45.0 t ha^{-1}, well above the values recorded in the literature, which range from 15.0 to 30.0 t ha^{-1} (Heredia Zárate & Vieira, 2005; Vieira et al., 2015; Moreno et al., 2017). Response to fertilization depends on climate, soil, crop management, irrigation, fertilization, and cultivar. However, adequate plant nutrition via organic and/or mineral fertilization may increase arrowroot production in the studied region, having as a stimulus the price of starch and the adaptation of the crop to family farming.

Furthermore, the export of relevant amounts of soil macronutrients by arrowroot rhizomes demonstrates the need to develop an adequate fertilization program for the crop, aiming at reaching its maximum yield capacity without loss of quality (Pereira, 2019). Brito et al. (2006) estimated the yield of sweet potato tuberous roots according to quadratic models, and observed a decrease in yield when using high rates of bovine manure, nitrogen, phosphorus, and potassium, respectively. The response of the crop to organic fertilization will depend on soil conditions, with the possibility of loss of nutrients and, consequently, economic losses and/or a decrease in rhizome yield when using rates above that which promotes maximum yield.

Conclusions

Field readings with SPAD 502 and Dualex on the second expanded leaf are efficient in diagnosing N status in arrowroot plants at 120 days after planting.

Arrowroot varieties 'Comum' and 'Seta' respond to nitrogen fertilization with bovine manure in a similar way in terms of nutritional status, rhizome yield, leaf nutrient content, and nutrient export by rhizomes.

The decreasing order of macro- and micronutrient exports by rhizomes of arrowroot varieties 'Comum' and 'Seta' is: K > N > P > S > Mg > Ca and Fe > Zn > Mn > Cu > B.

Commercial rhizome yields were 47.9 t ha^{-1} for variety 'Seta', with 778 kg ha^{-1} N; and 43.2 t ha^{-1} for variety 'Comum', with 900 kg ha^{-1} N.

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